Radial strip detectors in Allpix^2

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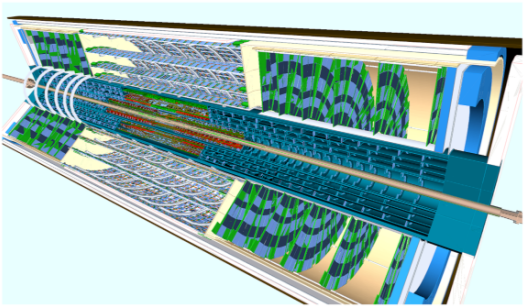
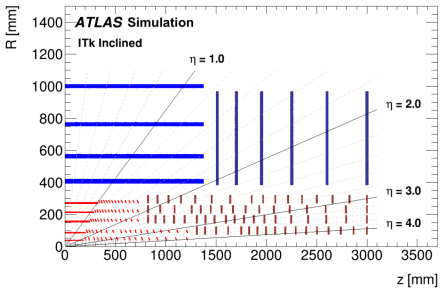
ATLAS ITk Strip detector

- ATLAS Inner Tracker (ITk) is the innermost (future) part of the ATLAS Detector.
- Critical for particle track and vertex reconstruction.
- Divided into two regions – barrel and end-cap.
- Utilizes two types of detectors – ITk Pixel and ITk Strip segments.

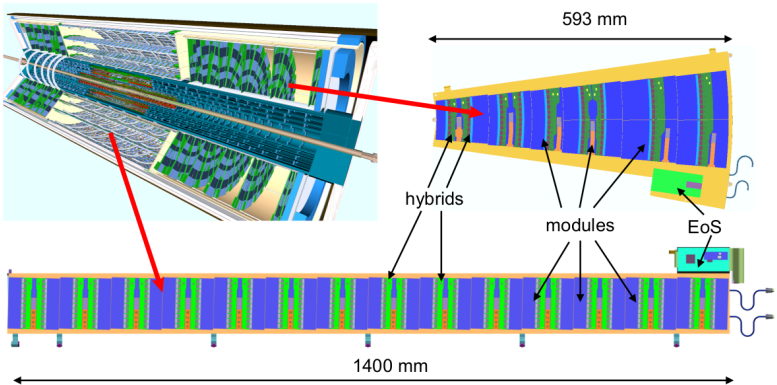


ATLAS ITk visualization.



ATLAS ITk layout: pixel modules in red, strip modules in blue.

- Barrel and end-cap strip modules differ in size and shape.
  - Barrel modules are rectangular and placed on "staves."
  - End-cap modules are trapezoidal, have various shapes (R0–R5) to fit onto a "petal."



Barrel and end-cap regions of the ITk. Barrel modules on a stave, end-cap modules on a petal.

ITk Barrel modules

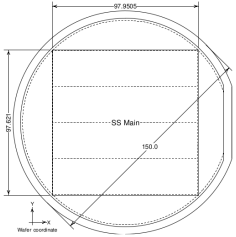


Fig.2 Barrel wafer layout: Short-strip (SS)

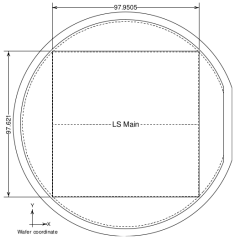


Fig.3 Barrel wafer layout: Long-strip (LS)

ITk End-cap modules

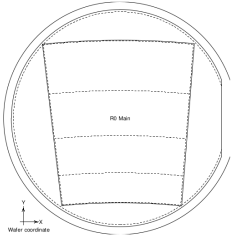


Fig.4 Endcap wafer layout: R0

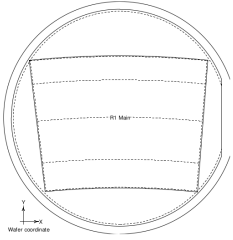


Fig.5 Endcap wafer layout: R1

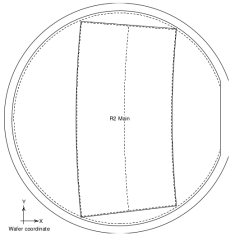


Fig.6 Endcap wafer layout: R2

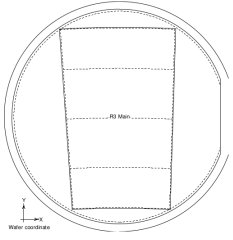


Fig.7 Endcap wafer layout: R3

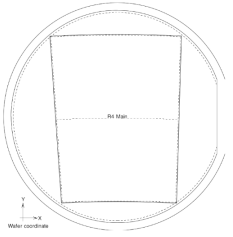


Fig.8 Endcap wafer layout: R4

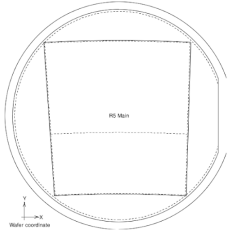
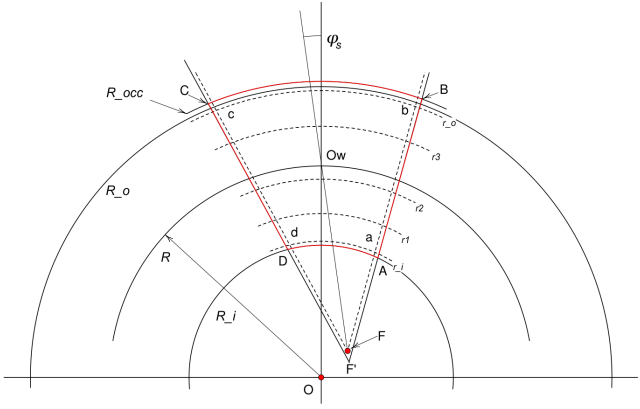


Fig.9 Endcap wafer layout: R5

- ATLAS ITk end-cap sensors feature the stereo angle:
  Strips do not point to the sensor origin O, but to a focus F. Point F is obtained by rotating point O around the sensor center Ow by the stereo angle φ_s.
- Critical for tracking performance of double-sided modules.
- Stereo angle is 20 mrad (1.15°) for every ITk strip end-cap sensor.



Radial strip detectors in Allpix^2

- Barrel strip detectors could be simulated, but radial end-cap ones couldn't be.

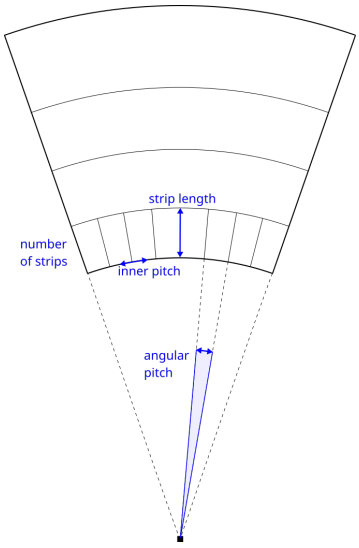
$\Rightarrow$ Limited scope of simulation studies of the ITk.

- Implementation of radial strip detectors via a new detector model class.
  - Fully functional, merged into `master` branch.
  - Example simulations included.
  - Documentation in an internal ATLAS note (CDS link).

- Radial detector models defined using 4 parameters for every strip row:
  - number of strips,
  - angular pitch,
  - inner pitch,
  - strip length.
- Model type defined as `"radial_strip"`.
- Optional definition of the stereo angle.
- Models of all ITk strip end-cap detectors created and can be used out-of-the-box.

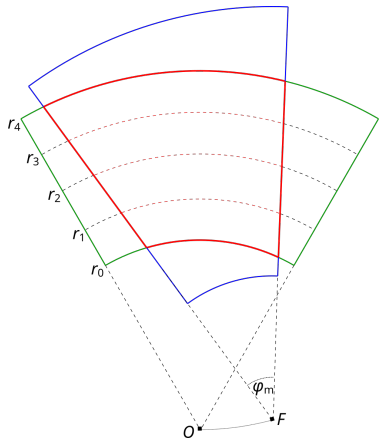
ATLAS ITk R0 model definition:

```
type = "radial_strip"

number_of_strips = 1026, 1026, 1154, 1154
angular_pitch = 0.193mrad, 0.193mrad, 0.171mrad, 0.171mrad
inner_pitch = 74.4um, 78.1um, 73.6um, 78.5um
strip_length = 19mm, 24mm, 29mm, 32mm
stereo_angle = 20mrad

sensor_thickness = 300um
```

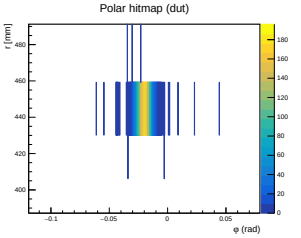


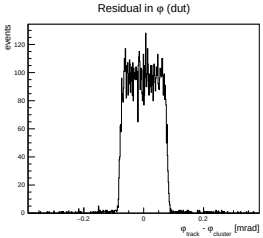
- Sensor geometry corresponds to the ITk strip end-cap design.
- Stereo angle properly reflected in the sensor shape.
- Sensor volume obtained as the intersection of two curved trapezoids:
  - One with proper radial dimensions and origin in O – defines strip rows.
  - One with proper angular dimensions and origin in F.

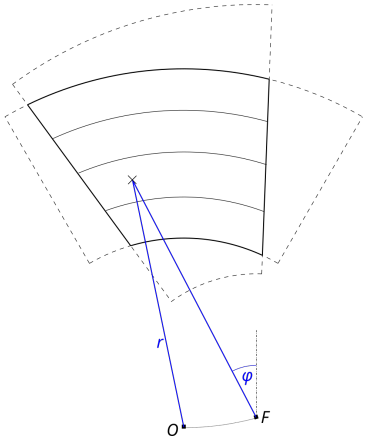
  $\Rightarrow$ Resulting shape has the proper radial and angular dimensions.



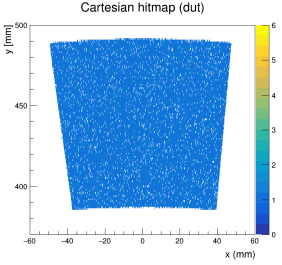
- Very beneficial to work in polar coordinates due to the sensor shape
- Stereo angle-related adjustments are necessary.
- Hit positions processing in polar coordinates $[r, \varphi]$ where
  - radial component r is measured from origin O,
  - angular component φ measured from focus F.
- Additional outputs and plots added to the framework (polar hitmap, r and φ residuals).

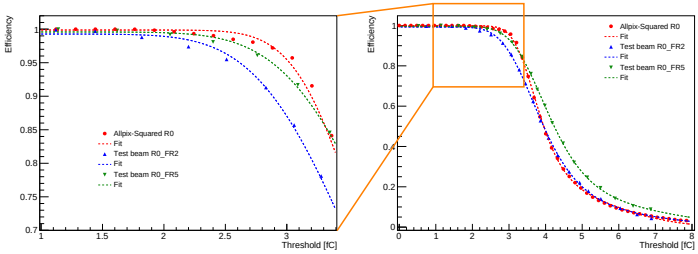






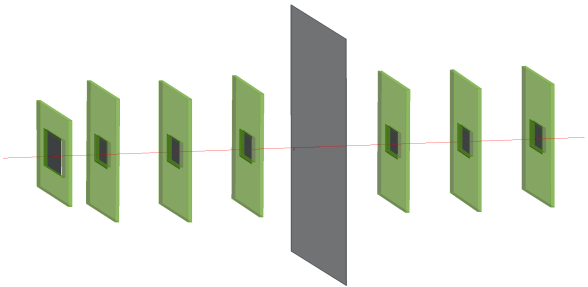
- Initial simulation with a large-diameter flat beam to map the detector geometry and test outputs.
  - Hitmap shows the correct skewed detector shape.
- Test-beam-like simulation with 5 GeV electron beam, comparison with available test beam data[1].
  - Comparison of detection efficiency as a function of charge threshold.
  - Agreement within variance due to different ASIC calibrations typically seen during TB measurements.





[1]The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

- Finished implementation is already being used for further studies.
- Full test beam simulation.
  - Proper detector setup with a telescope and a timing plane.
  - Track reconstruction and analysis using the Corryvreckan framework.
  - Comparison to additional test beam outputs.
  - Further validation of the implementation.
- ITk Strip end-cap System Test.



Summary

- Allpix^2 has been used for performance studies of ATLAS ITk strip modules.
- Great agreement of simulation results with prototype measurements.
- Simulations of radial end-cap strip detectors are now also possible.
  - Results in reasonable agreement with TB data.
- Implementation of radial detectors is already being used in other simulation studies.